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The Department Of Defense's Collaborative Combat Aircraft Program

Good News, Bad News, and Unanswered Questions

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Introduction: Big Problems with the Air Force Fighter Fleet

On September 22, 2021, General Mark D. Kelly, then commander of U.S. Air Combat Command, gave a **speech** with a grim recurring message: "Extensive analysis unambiguously shows that the current [U.S. Air Force] fighter fleet will not succeed" in plausible scenarios for a conflict with China in the Taiwan Strait.

Some of the extensive analysis that Kelly referred to was conducted by the Mitchell Institute for Aerospace Studies, which has since made its analysis public. The Mitchell Institute found that by 2022 the Air Force fleet was less than half the size it was in 1990, and roughly **80 percent** of Air Force fighters had already exceeded their designed service lives. In the Air Force fleet, the average fighter–not the design model, the actual aircraft–is about **30 years old**. According to the **Mitchell Institute report**, these aging aircraft are increasingly neither mission capable nor safe to fly, "because of their advanced age and systems and structures that are failing at increased rates." Purchases of new aircraft are not keeping up with the pace of the problem. The fleet has been getting older and smaller each year.

As General Kelly correctly pointed out, this is not a recipe for success in an era marked by renewed large-scale wars. Russia's invasion of Ukraine, backed by **China, Iran,** and **North Korea**, shows that the world is far from safe.

The Air Force needs more aircraft, but it also needs those aircraft to be cheaper to buy, fly, and repair. In 1985, **Norman Augustine** made his famous observation that each new generation of U.S. fighter aircraft costs vastly more than the one before. Since the time of the Wright brothers, the unit cost of new-generation fighter aircraft has increased, on average, more than **tenfold every 20 years**. This trend has been consistently observed across **more than 100 years** of data, finally bringing the U.S. Air Force budget to the breaking point. Air Force secretary Frank Kendall **said** in 2023 that the fighter aircraft component of the Next Generation Air Dominance program—the official follow on to the F-35—will cost "multiple hundreds of millions" of dollars per aircraft.

Not only are U.S. military airplanes more expensive, they also take longer to build. For example, 23 years after the Pentagon awarded the contract for the F-35, the program finally reached the status of full-rate production in 2024. Even now, new F-35 aircraft are delivered **two to three years** after the order is placed and paid for, even under favorable circumstances. This means that if the U.S. Air Force had ordered a large number of planes right after the start of Russia's February 2022 invasion of Ukraine, those planes would be rolling out of the factory right about now—and that is assuming that the order size is within the production capacity of the existing manufacturing supply chain, infrastructure, and labor force, which is sized to produce about **150 planes** per year. If the United States needed far more planes per year because, say, the Air Force was taking heavy losses in a shooting war with China, then it would likely be forced to wait far longer than two to three years, which could easily be too late.

The Solution: Autonomous Collaborative Combat Aircraft

Department of Defense (DOD) leadership has known for a long time that it must find a way to rapidly fill the large and growing hole in combat capacity without breaking the budget. For a decade, **DOD leadership** has spoken about the potential of artificial intelligence (AI) and autonomous technologies to help address this challenge. Designers of **autonomous aircraft** are unburdened by the engineering and cost disadvantages of accommodating flesh-and-bone pilots who need life support, flight controls, displays, and escape systems. Moreover, designing any new generation of aircraft would offer the DOD a chance to walk back from the "**jack-of-all-trades**" design philosophy that helped make the F-35 so costly, complicated, and unwieldy. Starting fresh offers the Air Force an opportunity to build larger quantities of cheaper autonomous aircraft. The Air Force **described** its goal for one early initiative in this area as "to break the escalating cost trajectory of tactically relevant aircraft."

However, many have **reasonably questioned** whether the Air Force was serious about moving toward an increasingly autonomous future. After all, decades ago the pilot-centric culture of Air Force leadership had made it a stubborn laggard in adopting **remotely crewed drones**. It was not much of a stretch to ask if history could repeat itself with AI-enabled and autonomous systems, especially since the past decade of Air Force budget requests had only modest investments in AI and autonomy, at least by the standards of major DOD initiatives.

In the spring of 2024, however, a definitive answer arrived in the form of a massive increase in the **funding** for a new autonomous fighter aircraft program called **Collaborative Combat Aircraft** (CCA). The Air Force aims to field **thousands** of more affordable, AI-enabled, autonomous, and uncrewed CCA aircraft that it hopes will operate alongside (and under the command of) pilots flying in fifth- and sixth-generation crewed fighters. CCAs will be autonomous in the sense that they can follow orders and take part in complex missions, including combat, without the need for step-by-step instructions. Air Force leadership **envisions** these aircraft as being capable of performing a diverse set of missions including electronic warfare; intelligence, surveillance, and reconnaissance; dogfighting; and more.

The Big Development for Collaborative Combat Aircraft

On April 24, 2024, the Air Force announced the most significant CCA milestone to date: a contract award that will take two companies, **Anduril** and **General Atomics**, to the next stage of the program. Each will **receive funding** "for detailed designs, manufacture, and [flight] testing of production representative test articles" in advance of a full-scale production contract. Thus, these latest contract awards will likely finalize the design of **Increment 1** of the CCA program. However, firms not selected to produce Increment 1 test articles **can still compete** for the future Increment 1 full-rate production contract expected in 2026 as well as the **Increment 2** effort now in the planning stages.

There is much to celebrate about the next phase of the CCA program. This paper focuses on four areas: First, the Air Force is finally devoting serious focus and funding to autonomous systems through an official program of record. These systems now have a clear path (at least budgetarily and bureaucratically) to moving out of DOD science project territory and into scaled operational deployment in combatant commands around the world.

Second, the Air Force's approach to acquisition and contracting for this effort finally fixes many of the failure modes of prior acquisitions—namely, that the requirements were **written so narrowly** as to limit innovative proposals from industry and that competition was closed off too early in the program life cycle to keep pushing industry aggressively forward.

Third, the government has separated the software and hardware acquisition pathways for CCA, which will allow the government to select the most attractive industry partners in each area, rather than having to pick a contractor team that might have attractive hardware and unattractive software or vice versa. The program's approach to an industry consortium developing and maintaining a government-owned **Autonomy-Government Reference Architecture** (A-GRA) also positions the government well to maintain industry competition and interoperability between this and other government autonomy efforts, including those outside the Air Force.

Fourth, the Air Force has selected a nontraditional venture capital-backed defense contractor, Anduril—an encouraging signal to other entrepreneurs and investors wondering whether they should spend any time or money developing technology for the DOD.

Good News: Serious Focus and Funding for Scaling Autonomous Systems

Unlike most other **DOD efforts** focused on AI-enabled and autonomous systems, **CCA** is a true **program of record** backed by significant multiyear funding and a path across the so-called **valley of death**, where most DOD technology development projects end, especially those run by the military service labs and research organizations in the Office of the Secretary of Defense.

In the DOD, very few big technological changes reach the warfighting community unless they are part of a military service program office.

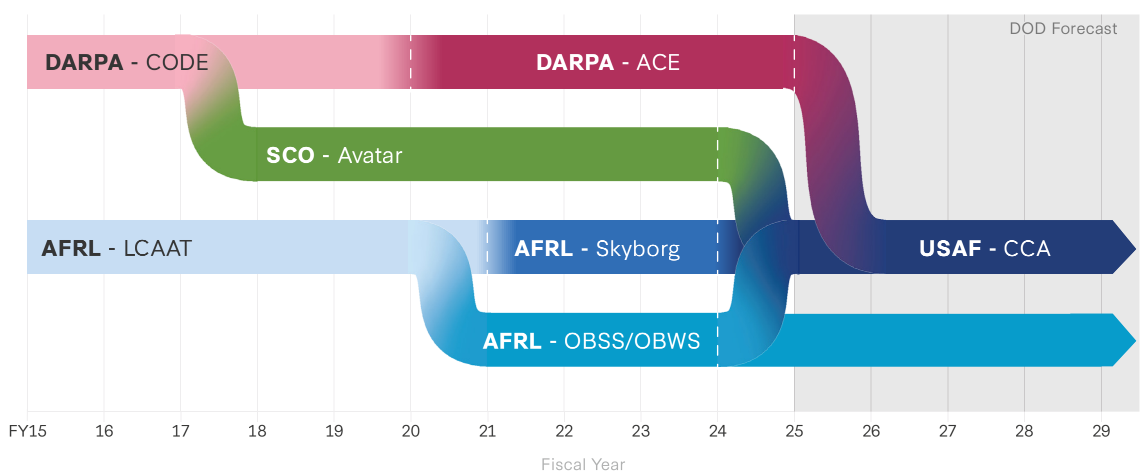
Being a program of record does not solve all problems; in fact, it causes plenty of bureaucratic headaches. But it does mean the responsible military service will devote serious time and energy to addressing all the thorny questions that need to be answered alongside development and even after development ends. These issues include, but are not limited to, doctrine, organization, training, matériel, leadership, personnel, facilities, and policy (**DOTMLPF-P**). In the case of CCA, the Air Force is spending tens of millions annually to address DOTMLPF-P questions through an **Experimental Operations Unit** (EOU) effort that will provide "operational concepts and studies, flight test and test support, prototypes, infrastructure investment for information technology, training and demonstration, and program management support to mature autonomous operational concepts."

The FY 2025 budget request included **$8.9 billion** for CCA over the next five years on top of the **$661 million** planned for FY 2024. That is a massive increase over what the DOD was previously spending on the precursor efforts to CCA.

Six earlier DOD research and development projects, listed below, meaningfully paved the way for CCA. See Appendix B for a more detailed description of each program and its relationship to CCA. See Figure 1 for a timeline of development and technology transition to the CCA program.

1. Defense Advanced Research Projects Agency (DARPA) Collaborative Operations in Denied Environment (CODE)
2. DARPA Air Combat Evolution (ACE)
3. Air Force Research Laboratory (AFRL) Low-Cost Attritable Aircraft Technology (LCAAT)
4. AFRL Skyborg
5. AFRL Off-Board Sensing Station (OBSS) / Off-Board Weapons Station (OBWS)
6. Strategic Capabilities Office (SCO) Avatar

Figure 1: Timeline of CCA and Its Key Precursor Programs

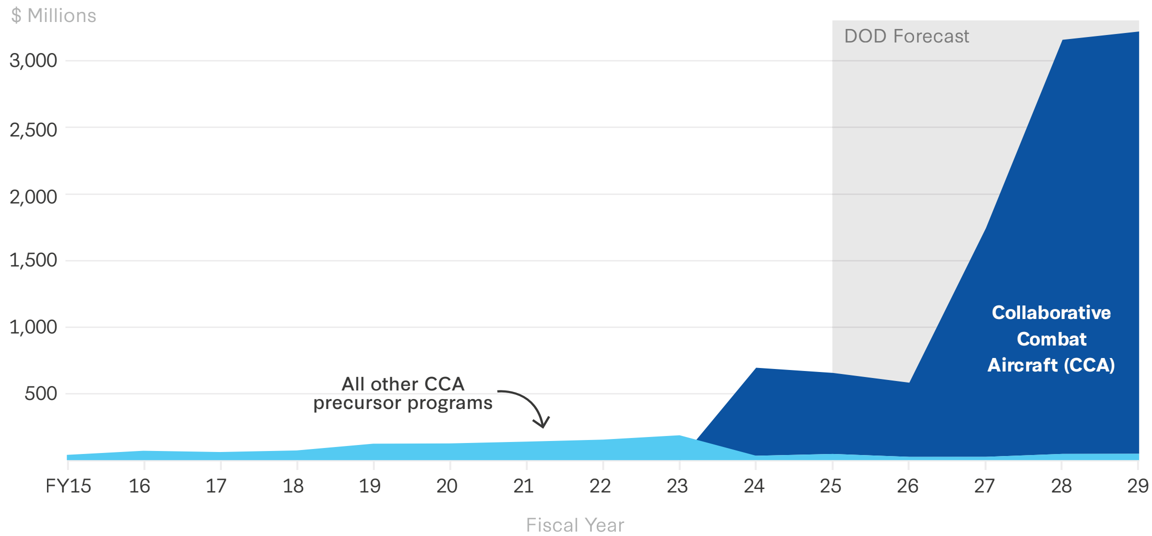


Note: This timeline is based upon when these programs had their official start and stop timeframes as listed in the Air Force Budget justification book. Actual transition between these programs and use of these program names by Air Force officials was less sharply delineated than depicted here.

Source: CSIS analysis of DOD FY 2015–FY 2029 research, development, test, and evaluation (RDT&E) budget requests, available at https://comptroller.defense.gov/Budget-Materials/.

These key precursor projects all did important technological maturation work to get the Air Force and its industrial base to the point where the CCA project was viable. But the CCA program will dwarf them in size. In fact, CCA will spend more in its first two years than the other six projects combined spent over the past 10 years (see Figure 2 and Appendix A) and will mark the program's transition from research and development to scaled production and sustainment.

Figure 2: DOD Spending on Selected Autonomous Aircraft Programs (FY 2015–FY 2029)



Note: The FY 2024 CCA figure includes a reported $150 million budget reprogramming request.

Source: CSIS analysis of DOD FY 2015–FY 2029 RDT&E budget requests.

Good News: A Commitment to Competition and Industry-Led Innovation

As Figures 1 and 2 show, the DOD—and the Air Force in particular—has been funding research and development for a low-cost autonomous fighter aircraft for about a decade. Given that, it would be understandable if government executives and experts had strong opinions about the most desirable aircraft design, cost, and capability profile. The risk—one that DOD executives have fallen prey to before—is that the government so over-specifies requirements for bidders that there is little to no opportunity for firms to demonstrate innovative system designs or engineering approaches.

With the most recent CCA contract award, the Air Force deliberately sought to give industry space to be creative. At a 2024 **CSIS event** before the award, Lieutenant General Richard Moore, deputy chief of staff for plans and programs for the Air Force, said,

> We want to go to them [industry] with questions and we want to find out what they can do, what is the art of the possible and what is it that they could provide, and let's allow the envelope to expand by not constraining it with a requirement.
>
> And I think what we're starting to see now is that there are a lot of thoughts out there, some of them from—not necessarily from the large defense primes—that really will be beyond what we would have conceived had we decided to write a requirement.

It is a positive sign that the Air Force kept an open mind as it considered proposals for how best to move into a more AI-enabled and autonomous future.

CCA also differs from many other recent programs of record in that it has an explicit focus on preserving continuous competition and opportunities for new entrants. While Anduril and General Atomics were selected to move forward with government funding and support, companies that lost this most recent phase of competition will still be eligible to compete for the upcoming production contract. An **Air Force statement** notes, "The broader industry partner vendor pool consisting of more than 20 companies" would be eligible for "future efforts, including future production contracts."

Figure 3 shows the pool of companies and other organizations that have been publicly acknowledged participants in CCA and its precursor programs. This is not a comprehensive list.

Figure 3: Organizations Publicly Disclosed as Working on CCA and Precursor Programs

CCA and Precursor Programs	Organizations		
AFRL - LCAAT*	• Kratos • General Atomics • Lockheed Martin	• Boeing • Aurora Flight Sciences	• Northrop Grumman
DARPA - ACE	• Leidos Dynetics • EpiSci • Shield AI (via acquisition of Heron Systems) • PhysicsAI	• Johns Hopkins Applied Physics Laboratory • SoarTech • Boeing • Lockheed Martin	• Calspan Corporation • Cubic Corporation
DARPA - CODE	• RTX (previously Raytheon) • Lockheed Martin		
AFRL - Skyborg	• Anduril (via acquisition of Blue Force Technologies) • LinQuest Corporation • Kratos • Boeing • General Atomics	• Leidos • Lockheed Martin • AeroVironment Inc. • Autonodyne LLC • BAE Systems • Fregata Systems	• NextGen Aeronautics • Sierra Technical Services
SCO - Avatar**	N/A		
Air Force - CCA***	• Anduril • General Atomics • Boeing	• Northrop Grumman • Lockheed Martin	
AFRL - OBSS/OBWS	• Kratos • General Atomics		

*Includes performers on LCAAPS and LCASD efforts.

**Performer data are unavailable due to the mostly classified nature of the effort.

***The Air Force recently announced it had awarded contracts to five vendors for the mission autonomy software portion of the program. These five companies had been kept classified for security reasons.

Source: Data compiled from program performer statements, government press releases, and federal contracting data from https://www.usaspending.gov/.

The emphasis on continuous competition means that the three companies that submitted bids for Increment 1 funding but were not selected–Boeing, Lockheed Martin, and Northrop Grumman–are still eligible to submit proposals for the Increment 1 full production contract. Those three firms, as well as firms not involved in Increment 1, will also be eligible to submit proposals for a future Increment 2 contract, whose timing is currently unclear. Increment 2 could have a very different set of **performance**

priorities. However, those companies would have to self-fund the two or more years of technological development that the government (at least in large part) will fund for Anduril and General Atomics.

Although this approach **has not been typical**, the DOD has tried it recently. It appears to be a valuable strategy in rewarding industry players willing to invest in technology research and development with their internal funds, not just those that participate only when the government reimburses all their costs. For example, in the area of space launch services, the Air Force and Space Force awarded Blue Origin for **Phase 1** and **Phase 3** of its National Security Space Launch contract but **not Phase 2**. After not being selected for Phase 2, Blue Origin was faced with either continuing to invest in technology development to serve the U.S. national security space customer base with its own funds or giving up on the market. In this case, not only was the potential for a future award attractive enough to keep Blue Origin investing, but the progress that Blue Origin made was appealing enough that the Space Force awarded it a spot on the program. Now Blue Origin and the other two contract awardees—SpaceX and United Launch Alliance (ULA)—will each face greater competitive pressure as they consider what price to charge and how hard to push their organization to meet the government customer's needs. That is a big win for the government.

With CCA, the Air Force has replicated that approach of **preserving opportunities** for competition and looks likely to reap the benefits. The other three companies that had previously received CCA money in FY 2024 have all said they will continue investing in autonomous aircraft technology and may bid on the next contract increment for the CCA program. Beyond those three firms are other companies that might bid on the next increment, such as Kratos, which was a major winner in both the **LCAAT** and **Skyborg** programs. Many more firms might serve as subcontractors to a prime contractor.

All of this suggests that the companies developing CCA are unlikely to be complacent anytime soon. They will continue to face meaningful competitive pressure, and the DOD still has the opportunity to benefit from firms that have relevant capabilities and are willing to invest their own money.

Good News: Separating Software and Hardware Acquisition Pathways

For the CCA program, the Air Force is running separate acquisition pathways for the hardware and software elements. While most of the attention in the policymaking community has focused on the hardware platforms that will serve as the basis for Increment 1 of the CCA program, Brigadier General Jason Voorheis, program executive officer for fighters and advanced aircraft, said that the Air Force has **signed contracts** with five companies to develop mission autonomy software. Thus far, the Air Force has not publicly disclosed what companies are involved for security classification reasons.

On the one hand, it might seem that the best performance would come from a vertically integrated provider of both hardware and software. There are certainly many examples where this seems to be the case. Apple, the designer of the iPhone and Mac computers, has long argued that its vertical integration of hardware and software designs **offers improved performance** in both areas. Apple also exerts **tight control** over its manufacturing supply chain, even though actual manufacturing is done by third-party companies. DJI, a Chinese producer of commercial drones that are **widely used** by both Russian and Ukrainian forces in their conflict, is **vertically integrated** and **dominates** the global market for consumer drones. More recently, and in the aerospace sector, SpaceX has had success with in-house development of both hardware and **software**.

However, separating the acquisition for hardware and software has several benefits for the government. First and foremost, it allows the national security customer to pursue the most compelling options in both aspects of the program. Were this not the case, the government might pick a suboptimal software provider because it found the hardware offering especially compelling—or vice versa. In the past, major acquisition programs run by hardware-first defense contractors have frequently been delayed due to **software challenges**. There are many parts of the DOD industrial base where the hardware part of the market **does not have** a deep bench of industry competitors. Getting into the hardware business for a given platform might be prohibitively risky or expensive for new market entrants, even if they have attractive offerings on the software side. Separating the competitions offers the government an attractive opportunity to increase competition, and there is a recent example that suggests separating hardware and software providers is feasible. In March 2024, Shield AI, a provider of autonomous flight software, successfully integrated its Hivemind AI Pilot software with the Kratos MQM-178 Firejet. Shield AI CEO Ryan Tseng **noted** that the integration took place in 180 days.

The Senate Armed Services Committee has expressed a strong preference for this approach; its version of the FY 2025 National Defense Authorization Act (NDAA) **included** the following provision: "The Secretary of Defense shall ensure that, to the maximum extent practicable, acquisition programs of the Department of Defense for autonomous unmanned aerial systems utilize separate, parallel acquisition pathways for hardware and software." The House **version** of the bill included a similar provision. This is not yet law, but the Air Force is already pursuing this approach regardless.

In addition to separating the acquisition of hardware and software, the CCA program has also taken a novel and promising approach to creating industry-developed but government-owned intellectual property in the form of an **Autonomy-Government Reference Architecture** (A-GRA). A **government reference architecture** is an authoritative source of information provided by the government that "guide[s] the system design, development, production, and sustainment processes" and "constrains the instantiations of multiple architectures and solutions."

The Air Force's assistant secretary for acquisition, technology and logistics, Andrew Hunter, **described** the CCA's A-GRA as "the government controls that defines standards and interfaces and interoperability among platforms." This is attractive because the standards and interfaces not only make it clear to industry vendors how to write new software and new capabilities that are compatible with the existing system; they also allow the system to be interoperable with other developments across the DOD. Navy leaders **have suggested** that their autonomous platform efforts will conform to the Air Force's A-GRA, ensuring interoperability between the services' software and platforms.

In the past, however, many government reference architectures have been supported by a single government or industry provider, which can lead them to be stagnant and overly reflective of the specialized expertise of a single organization. In the case of CCA's A-GRA, the government **formed an industry consortium** of more than 30 companies with a broad set of capabilities and perspectives. This also maximizes the readiness of these companies to bid on contracts that require adherence to the A-GRA and incentivizes them to participate actively in continuously improving the A-GRA.

The most important benefit of the Air Force's approach to this particular government reference architecture, however, is likely its modularity. The long-lead issue in updating the software of aircraft is often flightworthiness certification. Because this is a lengthy and labor-intensive process, it incentivizes both government and industry to freeze software development once flight certification has been obtained, which stifles innovation and performance improvement. In the case of CCA's A-GRA, however, the government can specify what aspects of the software are flight certified and largely unchanging and add bounded modules that do not put that certification at risk or can undergo separate certification. This both mitigates programmatic risk and accelerates innovation. For example, industry sources told CSIS **commercial companies have** successfully employed this open-architecture model on DOD programs, allowing them to plug and play new sensors and accompanying software without compromising the FAA flight certification of the entire system. Despite these positives, Air Force officials must remain vigilant to ensure that the A-GRA sticks to the mandate of setting standards for interoperability, and does not, as discussed above, stray into specifying overly restrictive requirements that limit industry's innovation opportunities.

Good News: A Willingness to Consider Nontraditional Defense Firms

Finally, it is encouraging to see the DOD's willingness to try out a nontraditional defense contractor in **Anduril**. For decades, the DOD **has lamented** the increasingly weak and **consolidated** competitive landscape of its supplier base. But for the competitive landscape to improve, new start-ups must attract investment to develop offerings that the DOD finds attractive, and at least some must receive financial rewards so that the venture capital community finds it worthwhile to keep investing in new firms. These new entrants are often especially well positioned to bring best practices and technologies from the commercial software sector, which are critical for AI and autonomy.

Following the success of government-focused firms such as Palantir and SpaceX, the venture capital community has in recent years shown **renewed interest** in funding aerospace and defense technology start-ups, but some investors caution that patience is wearing out. For example, in 2021, investor Katherine Boyle **wrote**, "After five years of DOD saying 'we want to work with the best startups,' we have, at most, two years before founders walk away and private capital dries up."

Anduril's victory on the most recent CCA program contract—and the opportunity for billions of dollars in revenue that it represents—will be a breath of fresh air to venture capital investors wondering whether to bother with the challenges of the defense market.

Two Bits of Bad News

Overall, this next stage of CCA is a very promising development for the future of Air Force autonomy. However, there are still some causes for concern. The Air Force statement accompanying the recent **CCA announcement** notes, "The CCA program aims to deliver at least 1,000 CCAs, prioritizing cost-effective scalability. . . . CCA offers expanded fighter capacity (affordable mass) at reduced costs and adaptable timelines." While these are admirable goals, the phrases "affordable mass" and "adaptable timelines" are not what they might at first seem.

Air Force secretary Frank Kendall addressed the cost, number, and time elements in his **recent testimony** before the House Appropriations Subcommittee on Defense, stating, "We'll have over 100 [CCAs] on order or delivered by the end of the [Future Years Defense Program]," in September 2029. In other words, the Air Force will likely not field CCAs in any meaningful number until the end of this decade—possibly longer if CCA follows the common DOD pattern of programmatic delays. This is concerning given intelligence community **reporting** that Xi Jinping, general secretary of the Chinese Communist Party, has instructed the Chinese military to be "ready by 2027 to conduct a successful invasion" of Taiwan.

The **2024 Senate draft of the NDAA** echoed these schedule concerns, stating, "the committee is concerned that the current [CCA] strategy does not prioritize fielding of tactically relevant aircraft at a low cost point on a timeline that matches current intelligence assessments."

As for the unit cost of CCAs, Kendall estimated each aircraft would cost $25–$30 million. The original vision of the LCAAT umbrella program, CCA's predecessor, was to **develop** a $3 million unit cost aircraft. Both numbers are dramatically cheaper than the F-35. Kendall's proposed figure is closer to the cost of some F-16 models and is roughly the **same cost** as an existing MQ-9 Reaper drone, which is admittedly designed and optimized for a very different mission.

- **F-35 Costs:** In recent purchases, each DOD F-35 cost **$80–$110 million**, not including the **massive costs** of research and development and, later, sustainment. According to **reporting** by *Fortune*, the price for "recent foreign sales have averaged out to between $150 million and $200 million per plane." Foreign sales prices arguably more accurately reflect earlier R&D costs, but they sometimes also include unspecified costs of infrastructure, training, and support services. This makes them difficult to compare on an apples-to-apples basis with DOD purchases.
- **F-16 Costs:** The F-16 program began in 1971. Coincidentally, the Air Force's original unit cost **estimate** for the F-16 was also $3 million, though that would be **$23 million** today after accounting for inflation. The Air Force no longer buys new F-16s, but some U.S. allies and partners do. An $800 million **Slovakian purchase** of 14 F-16s from six years ago suggests an F-16 unit cost of roughly $57 million, though this is for the newer variants with upgraded subsystems. Older F-16 variants are **reportedly** sold for $34 million.

In his testimony, Secretary Kendall reiterated that the Air Force ultimately aimed to field 1,000 CCAs or more but **strongly opposed** reinserting the $3 million unit price target on the systems as the U.S. House of Representatives sought to do in its version of the 2024 National Defense Authorization Act.

There are two concerns here. The first is that the institutional culture of the Air Force will drive CCA to replicate the expensive and exquisite approach that has been a hallmark of nearly every aircraft the Air Force and its major industry partners have designed in the past 50 years, including its uncrewed efforts. Removing the pilot from an aircraft design and the associated necessary equipment has (in principle) the potential to reduce the costs of an aircraft, but it is no guarantee the aircraft will be cheap. The Global Hawk drone, for example, has a unit cost that can be **$130 million** or higher, mostly because of the exquisite sensor payloads it carries and the low production volume.

Perhaps the Air Force is merely acknowledging that even a cheap plane outfitted with expensive sensors (perhaps paid for by a different part of the Air Force budget) will easily exceed a $25 million cost cap. However, the Air Force must find a way to prevent its existing acquisition culture from breaking everything that has the potential to make CCA such a special program.

Over the next few years, Air Force program managers will encounter lots of tempting opportunities—and perhaps even pressure from Congress—to make the CCA design slightly better performing for (supposedly) slightly more money and a slightly slower schedule. But giving in to those tempting opportunities will almost always be a mistake. As Air Force chief of staff David Allvin recently **said**, the CCA program should avoid tacking on "extra requirements like Christmas tree ornaments that make them so much more expensive." The Air Force already has expensive, high-performing fighter aircraft like the F-35. The point of the CCA is to be cheap, rapidly built, and numerous. This is not to say that the Air Force should tolerate lousy work on the part of its industry partners but merely that cost and schedule must always be kept firmly in focus.

The second cause for concern is that almost all of the cost-cutting conversation around CCA and its predecessors has revolved around sacrificing performance and lifespan rather than simply improving the operational efficiency of an aerospace and defense industrial base that is frequently bloated and sluggish. The cost savings from sacrificing performance and lifespan are real: an engine meant to last 50 years will, of course, cost more than one meant to last a few months. But this program is also an opportunity for the Air Force to demand better from industry and use competitive pressure to drive better results.

A helpful example comes once again from the space industry. United Launch Alliance (ULA), a joint venture of Lockheed Martin and Boeing, had a decade-long monopoly on government medium- and heavy-lift space launches from its formation in 2006 until **SpaceX** won its first Air Force launch contract in 2016. During a period when ULA sought to prevent SpaceX from competing for launches, ULA insisted that its prices, which were routinely two to six times what SpaceX charged, were essential to ensuring its admirable zero-failure safety record. Once SpaceX started taking significant market share—first at NASA and then with the Air Force—ULA hired a new chief executive officer who promised to cut prices in half within two years without sacrificing safety, speed, or quality. ULA missed that cost-cutting target but **came close**, without a single launch failure or significant schedule delay. ULA even remained **significantly profitable**.

While ULA deserves credit, its successful cost-cutting and SpaceX's initial success with building to a much lower cost structure illustrate why the DOD should be skeptical when companies claim they are already operating at maximum efficiency and that cost decreases are achievable only by sacrificing performance and reliability. ULA was clearly capable of being significantly cheaper without sacrificing performance.

An even stronger example of how SpaceX forced NASA to reexamine its cost assumptions comes from the development of the Falcon 9 space launch vehicle. According to a **NASA review** of SpaceX's finances and costs, the entire development cost of the Falcon 9 (including the predecessor Falcon 1) was $400 million. After 2010, NASA took the performance parameters of the Falcon 9 launch vehicle and input them into its NASA-Air Force Cost Model (NAFCOM), a common tool used in predicting the cost of government space systems. NASA was trying to assess how well NAFCOM could predict the cost of SpaceX's launch vehicle under normal government program management assumptions. The result? NAFCOM **predicted** development of the Falcon 9 alone would cost $3.977 billion under the typical NASA environment and culture, more than 10 times the amount SpaceX actually spent. NASA further predicted that a more commercially oriented program management approach would still cost $1.7 billion, more than four times what SpaceX actually spent. The point is that the cost models NASA and the Air Force used to set cost targets had failed to imagine pathways to remarkably improved cost efficiency—without compromising performance or schedule—were even possible until they saw an existence proof in the form of SpaceX's ultra-cheap Falcon 9.

There is reason to suspect that Air Force cost modeling in fighter aircraft is at risk of becoming similarly complacent. During a 2020 event, Dr. Doug Meador, who served as deputy program manager of AFRL's LCAAT umbrella program, **stated**,

> Traditional [Air Force fighter] cost models . . . if we use them in their current state, would actually make these aircraft very expensive. If we're going to bend the cost curve, we have to bend the cost model with it. . . . One of the best predictors of aircraft cost is weight, and with the current cost models we have, we're essentially restricted to "the only path to cheaper is to get lighter." So we're leveraging commercial processes . . . to drop that price-per-pound cost-estimating relationship way down so we can again work to cost targets. . . . Cost is actually the key performance parameter that we start from [in attritable fighter aircraft research and] that we try to squeeze the most performance out of.

As previously noted, Secretary Kendall has expressed **strong opposition** to the original $3 million cost target of the LCAAT program and is instead speaking of CCA aircraft with a unit cost of around $25 million. Whether or not he is correct is beyond the scope of this paper. Based on the weapons and sensors a given CCA comes with, $25 million may be **perfectly appropriate**. However, the Air Force should not concede to a $25 million unit cost before it has asked itself and its industry partners whether they have considered the low-hanging fruit of cost reduction.

For example, during SpaceX's first 15 years, all of its manufacturing was done out of a single facility in California, with SpaceX itself, not subcontractors, contributing **70 percent** of the value of each vehicle. SpaceX's head of manufacturing was a **former BMW automotive executive** and not from a legacy aerospace contractor. Repeatedly, SpaceX leaders emphasized how these and other factors contributed to the company's low costs. Legacy aerospace program management practices are often quite different. For example, the **F-35 program marketing website** brags that the aircraft has more than 1,900 suppliers who perform work in 48 out of 50 U.S. states. It stretches credulity that this is the cheapest or fastest way to do business. Spreading the money around is a political strategy, not an industrial one. For the CCA program—indeed for all new DOD programs upon which U.S. national security depends—this must change.

Unanswered Question: Is the CCA an Autonomous or Semi-autonomous Weapon System?

While the CCA system is clearly targeting a meaningful increase in the level of autonomous capability, the involvement of a human pilot in the control loop suggests that CCAs may not technically meet the **DOD policy definition** of an "autonomous weapon system," though this may change over the life of the program. According to DOD Directive 3000.09, an autonomous weapon system is defined as one that, "once activated, can select and engage targets without further intervention by an operator."

The distinction of "autonomous" and "autonomous weapon system" might strike some as pedantic. However, it is important to distinguish what level of autonomy raises meaningful legal and ethical questions and what level is more or less the policy equivalent to what the department has been doing for nearly 70 years since the introduction of **heat-seeking missiles**. In the case of CCA, going from mostly autonomous–but with exclusive human control over decisions around selecting and engaging targets–to being an autonomous weapon system in the formal sense of that term could be a relatively minor software update from an engineering perspective. Bureaucratically and politically, though, it would be **no small task**. Getting approval to begin development of an autonomous weapon system requires going through the DOD Directive 3000.09 senior review process, which mandates an exhaustive analysis and signoff by three of the six most powerful people in the entire department.

While the government has not stated whether or not the CCA will go through this **senior review process**, the same "bounded approval" benefits mentioned earlier in this paper apply as in the case of airworthiness certification.

Unanswered Question: Even with CCA, Is the Air Force Changing Fast Enough for a New Era of Military Technology Competition Where China's Strengths Are Considerable?

So far, this paper has praised the new approach exemplified in the CCA program. Overall, the Air Force does appear willing to make big bets on a military technology paradigm where low costs and greater quantities of lower performing aircraft are the primary source of military advantage. This is a marked change from the world of small numbers of expensive and exquisite aircraft. That world drew upon the United States' strengths as the wealthiest and most technologically advanced country in the world. Just as importantly, though, that paradigm appeared to accurately reflect the optimal military approach. It was to the United States' geostrategic advantage that small numbers of expensive but highly capable systems could reliably defeat large numbers of less capable systems, often with few casualties.

The new world might favor a new military technology paradigm, one where military systems draw more heavily upon widely available and less expensive commercial technologies. This new world may not play to the United States' geostrategic strengths–at least in comparison to China. After all, China is the world's largest manufacturer with the **greatest overall industrial capacity**. And, China's industrial base has climbed the ladder of technological sophistication to the point where it is competitive even in industries, such as the automotive sector, where previous Chinese offerings were **low performing and unattractive** even at greatly reduced prices. Of special note, China's autonomous car industry has made **significant progress**, and industry sources told CSIS that Chinese hardware and software capabilities for autonomous cars are often superior to American equivalents. The U.S. government has been **greatly focused** on America's leadership in frontier AI research, exemplified by large language models like ChatGPT, but AI's implications for autonomy–where China is already strong–might have the greatest near-term military significance.

The United States' edge over China in commercial manufacturing is–like the military domain–strongest in producing low numbers of expensive exquisite systems, like the ultra-precise machines that **power semiconductor factories** around the world.

The CCA program and others like it, such as the **Replicator initiative**, show that the DOD is trying to change and maintain its competitiveness in a new military technology equilibrium where mass once again matters. Deputy Secretary of Defense Kathleen Hicks said as much when she announced

Replicator, saying that "Replicator is meant to help us overcome the PRC's [People's Republic of China] biggest advantage, which is mass. . . . More ships. More missiles. More people."

The DOD deserves credit for finally making the large-scale investments needed to change. These are changes that **prior DOD leaders** have been arguing in favor of for a decade. Current DOD leaders have also expressed a willingness to change further: Secretary Kendall **said** in July 2024 that the Air Force was "tak[ing] a few months right now to figure out whether we've got the right design and make sure we're on the right course" on the Next Generation Air Dominance program. Earlier that month, Kendall had **said** that he was only "reasonably confident" that the sixth-generation fighter that would succeed the F-35 would have a pilot. Combined, this suggests that the Air Force is at least considering a future where essentially all new fighter aircraft development is focused around unmanned and autonomous systems.

Threading the needle between cost and performance is a delicate act, but the Air Force will have to work diligently with industry partners to find the right knee in the curve: vastly cheaper, somewhat lower performing (per aircraft), but overall a force that can deter and, if necessary, defeat China.

Despite these encouraging signs, the question remains, however, whether the DOD is changing fast enough to sustain its long-standing military edge in a future competitive landscape where China's advantages are **relevant and considerable**.

But the DOD has no choice. Whether or not the new locus of military power favors the United States' current advantages, it is coming nonetheless. Autonomous technologies and the return of mass will transform warfare whether or not the United States leads this change.

A helpful analogy comes from the internet's disruption of retail bookstores. In response to concerns about Amazon's increasingly dominant position in the book distribution market at the expense of brick and mortar bookstores, then-Amazon CEO Jeff Bezos **said**, "Amazon isn't happening to the book business. The future is happening to the book business."

The same is true of the current moment in military technology. Relying on small numbers of exquisite and increasingly expensive warfighting platforms simply is not a recipe for success in a potential conflict against an adversary such as China. Strong supporting evidence of this fact comes from David Ochmanek, the former deputy assistant secretary of defense for strategy and force development. Now at RAND, Ochmanek ran a series of wargames on behalf of the Joint Chiefs of Staff evaluating scenarios for a U.S.-China conflict. He colorfully summarized the **results of his analysis** as the United States "gets its ass handed to it."

For the DOD, this means that there is no time to waste. When it comes to CCA, the Air Force should keep its foot on the accelerator in terms of cost, schedule, and performance. It must also provide the competitive and financial incentives required to ensure companies do not grow complacent. Air Force leaders should also push companies to make the right choice for the program and for national security, even when it is politically inconvenient. This will require leaders in the DOD and Congress to show some courage. To borrow a phrase from the chairman of the Joint Chiefs of Staff, General C. Q. Brown, the DOD and its partners in Congress and industry must "**Accelerate Change or Lose**." ■

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Appendix A

Table 1: DOD Spending on Selected Autonomous Aircraft Programs (FY 2015–FY 2024)

	Historical Spending ($M)										Total ($M)	Total (%)
	FY 15	FY 16	FY 17	FY 18	FY 19	FY 20	FY 21	FY 22	FY 23	FY 24	FY 15–24	
DARPA – ACE	–	0.0	0.0	0.0	0.0	12.8	28.6	22.7	20.1	19.6	103.8	5.8%
DARPA – CODE	19.0	28.5	28.8	30.1	5.0	0.0	0.0	0.0	0.0	0.0	111.4	6.3%
AFRL – Skyborg	–	0.0	0.0	0.0	0.0	0.0	45.1	54.0	151.9	0.0	251.0	14.1%
AFRL – LCAAT	39.2	70.1	60.6	48.1	48.6	52.3	0.0	0.0	0.0	0.0	318.9	18.0%
SCO – Avatar	–	0.0	0.0	24.4	74.6	60.2	30.6	38.9	11.2	0.0	239.8	13.5%
AFRL – OBSS/ OBWS	–	0.0	0.0	0.0	0.0	0.0	34.3	38.2	3.4	13.0	88.9	5.0%
Air Force – CCA	–	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	661.0	661.0	37.2%
Total	**58.2**	**98.7**	**89.4**	**102.6**	**128.2**	**125.3**	**138.7**	**153.8**	**186.5**	**693.7**	**1,774.9**	**100%**

Note: The FY 2024 CCA figure includes a reported $150 million budget reprogramming request.

Source: CSIS analysis of DOD FY 2015–FY 2029 RDT&E budget requests.

Table 2: DOD Spending on Selected Autonomous Aircraft Programs (FY 2025–FY 2029)

	Future Budget Request ($M)					Total ($M)	Total (%)
	FY 25	FY 26	FY 27	FY 28	FY 27	FY 25–29	
DARPA – ACE	8.0	0.0	0.0	0.0	0.0	8.0	0.1%
DARPA – CODE	0.0	0.0	0.0	0.0	0.0	0.0	0.0%
AFRL – Skyborg	0.0	0.0	0.0	0.0	0.0	0.0	0.0%
AFRL – LCAAT	0.0	0.0	0.0	0.0	0.0	0.0	0.0%
SCO – Avatar	0.0	0.0	0.0	0.0	0.0	0.0	0.0%
AFRL – OBSS/OBWS	38.2	24.3	24.6	46.7	47.7	181.4	1.9%
Air Force – CCA	608.8	557.1	1,717.6	3,110.2	3,171.5	9,165.3	98.0%
Total ($M)	**655**	**581.4**	**1,742.2**	**3,156.9**	**3,219.2**	**9,354.7**	**100%**

Source: CSIS analysis of DOD FY 2015–FY 2029 RDT&E budget requests.

Table 3: Autonomous Aircraft Budget Line Items

CSIS TAG	Program Element (Number/Name)	Project	Accomplishments/Planned Programs
DARPA - ACE	PE 0603766E	NET-01	Air Combat Evolution (ACE)
DARPA - CODE	PE 0603286E	N/A	Collaborative Operations in Denied Environment (CODE)
SCO - Avatar	PE 0604250D8Z	250	Avatar
Air Force - CCA*	PE 0207110F	647123	Collaborative Combat Aircraft
	PE 0207179F	643721	Experimental Operations Unit (EOU)
	PE 0207179F	645340	Viper Experimentation and Next-gen Operations Model (VENOM)
AFRL - LCAAT **	PE 0603456F	635327	Battlespace Acoustics
	PE 0603211F	634920	Aerospace Vehicle Technology Integration
	PE 0603211F	634920	Advanced Aerospace Structure Technologies
	PE 0603211F	634927	Autonomous Systems Control
	PE 0603216F	634921	Missile/Remotely Piloted Aircraft Engine Performance
AFRL - OBSS/OBWS***	PE 0603211F	634920	Advanced Aerospace Structure Technologies
	PE 0603211F	634920	Aerospace Vehicle Technology Integration
AFRL - Skyborg****	PE 0603032F	N/A	Skyborg
	PE 0207179F	647123	Autonomous Collaborative Technologies
	PE 0603211F	634920	Aerospace Vehicle Technology Integration [Congressional Add: Unmanned adversary air platform]
	PE 0604858F	645350	Experimentation campaigns
	PE 0604858F	645351	N/A

*Work performed under PE 0207179F / Autonomous Collaborative Platforms, Projects 643721 / Experimental Operations Unit (EOU), 645340: Viper Experimentation and Next-Gen Operations Model (VENOM), and 647123: Autonomous Collaborative Technologies is explicitly acknowledged as connected to CCA in USAF RDT&E documents. For example, the FY 2025 request notes the EOU served "as early risk reduction for employment of CCA with crewed aircraft to mature operational concept development and evaluate supporting force structure to execute CCA operations."

**LCAAT funding includes only those PE codes and projects in the USAF RDT&E budget explicitly acknowledged as Skyborg precursors in the FY 2021 request.

***While Air Force budget documents do not explicitly list the OBSS or OBWS program under a specific program element, a FY 2022 DOD report to Congress lists OBSS as funded under PE 0603211F. Accomplishment descriptions under that PE in the following years describe activities related to OBSS and OBWS. For example, the FY 2025 USAF budget request describes work performed under PE 0603211F as follows: "Complete the fabrication and continue flight test of a sensor variant of a low-cost unmanned aerospace system. Continue the development of technology demonstrations for a forward weapons employment derivative of a low-cost unmanned aerospace system."

****Work performed under PE 0207179F / Autonomous Collaborative Platforms, Accomplishments / Planned Program: Autonomous Collaborative Platform; PE 0604858F / Tech Transition Program, Project 645351 / Prototyping and Project 645350 / Experimentation, and the Congressional Addition Related to Unmanned Adversary Air Platforms under PE 0603211F / Aerospace Technology Dev/Demo, 634920 / Flight Vehicle Tech Integration is explicitly connected to Skyborg in USAF RDT&E documents. For example, the FY 2024 USAF RDT&E request notes ADAIR work under PE 0604858F / Tech Transition Program, Project 645350 / Experimentation will "build and execute operational experimentation efforts focused on the implementation of Collaborative Combat Aircraft (CCA). . . . This will transition advancements pioneered through the Skyborg effort and industry advancements to produce initial fielded capability."

Source: CSIS analysis of DOD FY 2015–FY 2029 RDT&E budget requests.

Appendix B

1. **Defense Advanced Research Projects Agency (DARPA) Collaborative Operations in Denied Environment (CODE)** was a program designed to develop new algorithms and software to improve unmanned systems' ability to conduct operations in denied or contested airspace. This effort had a specific focus on developing collaborative autonomy that would allow multiple unmanned systems to be supervised by a single operator. CODE reportedly transitioned technology to the Strategic Capabilities Office (SCO) Avatar program and was succeeded by the DARPA Air Combat Evolution program discussed below.
2. **DARPA Air Combat Evolution (ACE)** was a **program** designed to develop and test AI algorithms for aerial combat operations, including fighter aircraft dogfighting against human pilots and human-machine collaboration, initially in simulation and ultimately in full-scale vehicles (modified F-16 aircraft).
3. **Air Force Research Laboratory (AFRL) Low-Cost Attritable Aircraft Technology (LCAAT)** was an AFRL-led umbrella research program covering materials, propulsion, electronics, sensors, flight control software, and more to develop new, low-cost autonomous aircraft. This program contained two subordinate **research initiatives**:
   - The **Low-Cost Attritable Aircraft Platform Sharing** (LCAAPS) program funded **General Atomics'** development and was an important precursor to the **Off-Board Sensing Station** project (discussed below). LCAAPS's goal was to develop an open-architecture aircraft that could have different variants suitable for different missions.
   - The **Low-Cost Attritable Strike Demonstrator** (LCASD) resulted in the delivery of the **XQ-58 aircraft**, "a low cost, high performance unmanned air vehicle developed through an Air Force Research Laboratory partnership with Kratos Defense & Security Solutions." The XQ-58 / XQ-58A work was later transitioned to the **Skyborg program**.
4. **AFRL Skyborg** was a direct programmatic successor to the LCAAT program as the AFRL umbrella program for attritable autonomous aircraft, reflecting increased technology readiness and the desire to move to more live-flight testing and experimentation. The Air Force designated Skyborg a **Vanguard program** in 2019, awarded the major Skyborg **indefinite-delivery / indefinite-quantity** (IDIQ) contract vehicle in July 2020, and **added vendors** in September 2020. Skyborg first received its own program element number in the Air Force budget in the

FY 2021 request. In the budget request, the Air Force provided a list of precursor programs and projects that were being realigned under Skyborg.

Blue Force Technologies, a firm acquired by Anduril in 2023, won a position on the Skyborg IDIQ contract in 2020 for work on its Fury aircraft, which was also part of the AFRL / Air Combat Command **Bandit Program** to **simulate adversary aircraft** in training exercises. Originally, Blue Force Technologies' funding was focused on aircraft hardware development and largely omitted software. By contrast, General Atomics was **funded through Skyborg** to work on the Autonomous Core System, a software "**brain**" that could work on multiple unmanned aircraft. The Fury aircraft served as the starting point for Anduril's bid on the CCA program.

5. **AFRL Off-Board Sensing Station (OBSS) / Off-Board Weapons Station** (OBWS) had the basic goal of furthering the ideas from the LCAAPS effort to develop an open-architecture aircraft that could have different variants suitable for different missions. Many details of the **OBSS/OBWS** program are classified. According to a February 2024 **AFRL press release**, "The OBSS was viewed as slower while carrying sensors but [had] longer endurance, while the OBWS was considered faster and more maneuverable, with less endurance but better range." General Atomics has been a part of the effort since its inception in late 2021 with the XQ-67 platform, which, along with the Autonomous Core System and its **Gambit series** of aircraft, was the basis of General Atomics' bid on the CCA program.
6. **Strategic Capabilities Office (SCO) Avatar** was a closely related **companion project** of LCAAT run by SCO that transitioned significant technology to both Skyborg and CCA. Most details of this program are classified.